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# Lung ultrasonography for early detection of extravascular lung water overload in intensive care patients early after surgery: a preliminary study

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## ABSTRACT

Aim. To investigate whether lung ultrasound can be used to detect extravascular lung water overload in the intensive care unit early after surgery.
Methods. This prospective study involved 60 patients without known cardiac or pulmonary diseases admitted to the intensive care unit at our Hospital after elective abdominal or vascular surgery. PaO2/FiO2 ratio, and appearance of B-lines were determined upon admission to the intensive care unit and at 6, 12, and 24 h later. Fluid overload was defined as the presence of B-lines ≤7 mm. Tissue oxygenation impairment was defined as a PaO2/FiO2 ratio < 200.
Results. Fluid overload was detected in 42 patients (70%). The dense B-lines predicted fluid overload around the same time as drop of PaO2/FiO2 ratio ($p = 0.115$). Appearance of dense B lines correlated strongly with PaO2/FiO2 ratio ($p < 0.001$).
Conclusion. Our preliminary results suggest that lung ultrasonography may be a promising non-invasive method for early detection of extravascular lung water overload in spontaneous breathing intensive care patients soon after surgery. Our findings should be verified in larger studies.

## INTRODUCTION

Fluid replacement therapy is unavoidable during surgery. Monitoring of fluid status in the patient is important for ensuring a fluid volume that is adequate but not excessive, since too much fluid can cause tissue edema that compromises microcirculation and disturbs gas exchange in the lungs (1). Postoperative pulmonary edema is a well-known postoperative complication with little known etiology and mortality (2,3,4). Even though it is difficult to identify the exact etiological factors, hydrostatic pulmonary edema is commonly seen. Water that is contained in the lungs outside the pulmonary vasculature is known as extravascular lung water (EVLW) (5). An increase in EVLW is the pathophysiological hallmark of hydrostatic pulmonary edema (6). In lung edema, EVLW increases either because of increased lung permeability or because of increased hydrostatic pressure in the pulmonary capillaries, or both (7). Assessment and monitoring of EVLW traditionally has relied upon invasive computed tomography (CT) or pulse counter cardiac output testing (PiCCO). A less invasive alternative is the P/F ratio, but this is less accurate. A potentially superior non-invasive procedure is ultrasound, which can be used to measure the dimensions of the inferior vena cava, right heart chambers and left ventricle (8), as well as estimate EVLW through visualization of lung parenchyma (9). Since ultrasound waves are completely reflected by air, they cannot image the lung parenchyma when it is full, but they can image the parenchyma when interstitial-alveolar imbibition occurs (10). This gives rise to characteristic vertical artifacts called “B-lines” (or “lung rockets”) that extend from the pleura to the edge of the screen (8,11,12). The number of B-lines is directly proportional to the degree of lung aeration loss and to EVLW volume (9).
Using lung ultrasound B-lines to detect EVLW has not been tested extensively, nor has it been compared with the conventional index of P/F ratio. If it allowed EVLW assessment, lung ultrasonography would become even more beneficial in the clinical setting: the technique is already used to confirm diagnoses of pneumothorax, interstitial syndrome and pleural effusion (13), as well as to distinguish among serious thoracic disorders (14,15,16).
The present study compared the ability of P/F measurements and lung ultrasonography to detect EVLW soon after major abdominal or vascular surgery.

## PATIENTS AND METHODS

### Patients

Patients older than 18 years admitted to the intensive care unit at Clinical Hospital Sveti Duh (Zagreb, Croatia) following elective abdominal or vascular surgery between April and November 2015 were prospectively enrolled in the study, as long as they had no known cardiac or pulmonary diseases, and lung ultrasonography showed bilateral diffuse distribution. The Ethics Committee of Clinical Hospital Sveti Duh approved this study and the requirement for informed consent.

### Procedures

After receiving general anesthesia, all patients received an endotracheal tube. After co-induction, anesthesia was maintained using a combination of inhalation anesthetic and intravenous drugs. Protective ventilation was combined with low flow. During surgery, all patients received Plasma Lyte 148 (pH 7.4; Viaflo, Baxter, Deerfield, IL, USA) at 6-8 ml/kg/h. Norepinephrine was administered at doses of 0.05-0.1 mcg/kg/min when needed to maintain mean arterial pressure over 60 mmHg. Packed red blood cells were used when hemoglobin concentration was ≤8.0 g/dl. At the end of anesthesia, patients were subjected to the recruitment maneuver.
After surgery, patients were admitted to the intensive care unit and given crystalloid Plasma Lyte at 1.5 ml/kg/h. At 24 h after surgery, all patients received the diuretic furosemide (20 mg).

### Data collection

Data on P/F ratio, and occurrence of dense B-lines were monitored upon admission to the intensive care unit (baseline), as well as at 6, 12 and 24 h after admission. All measurements were done with the patients in the supine position.

A decrease in P/F ratio below 200 was taken to indicate a rise of EVLW above 10 ml/kg (17,18,19,20); this cut-off indicates >20% shunting (21). The appearance of "dense B-lines" on lung ultrasonography, defined as lines ≤7 mm apart, was also considered a sign of incipient increase in EVLW volume (8,22). Taking P/F ratio as the reference method, we assessed the ability of dense B-lines, alone, to diagnose EVLW.

#### Statistical analysis

Statistical analysis was performed using SPSS 13 (Armonk, NY,USA). Independent-sample t tests were used to assess the significance of differences within groups for each set of measurements separately. The threshold of significance was $p < 0.05$. Possible correlation of P/F ratio with occurrence of dense B-lines was assessed using the chi-squared test.

## RESULTS

Of the 71 patients recruited during the study period, 11 were excluded because they developed atrial fibrillation soon after surgery (n = 6), had unilateral ultrasound signs of interstitial syndrome (n = 2), were discharged from the intensive care unit on the same day as surgery (n = 2), or requested immediate re-operation (n = 1). The remaining 60 patients (13 women) were analyzed (Table 1).

*Table 1. Demographic and surgical data on patients admitted to the intensive care unit after abdominal or vascular surgery*

| Characteristic | Value |
|---|---|
| N | 60 |
| Age, yr | 64±10.18 |
| Gender, women/men | 13/47 |
| ASA score, I/II/III | 33/21/6 |
| Surgery type, abdominal/vascular | 46/14 |
| Mean surgery duration, min | 148±33 |

ASA, American Society of Anesthesiologists
Values shown are n, or mean ± SD

No signs of fluid overload were detected in 18 of 60 patients (30%) based on P/F ratio, dense B-lines or IVCcl. In the remaining 42 cases, the combination of dense B-lines and IVCcl ≤40% predicted fluid overload before P/F ratio (7 of 42 cases), at the same time as P/F ratio (17 of 42) or after P/F ratio (18 of 42). Overall, the two techniques predicted EVLW at similar time points ($p = 0.115$).

Next, we examined individual correlation of decreased P/F ratio with the appearance of dense B-lines. Appearance of dense B-lines coincided with decreased P/F ratio in 26 of 42 cases, whereas it preceded the P/F decrease in 9 cases or trailed behind the P/F decrease in 8 cases. At all time points, decreased P/F ratio correlated with the appearance of dense B-lines: baseline, $\chi2 = 45.6$, df = 1, $p < 0.001$; at 6 h, $\chi2 = 37.686$, df = 1, $p < 0.001$; at 12 h, $\chi2 = 38.663$, df = 1, $p < 0.001$; and at 24 h, $\chi2 = 25.313$, df = 1, $p < 0.001$.

The total number of patients showing dense B lines grew faster than those with P/F ratio < 200 as time went on in the intensive care unit: baseline, 10 patients vs 3 patients; 6 h, 10 vs 6; 12 h, 26 vs 1; and 24 h, 36 vs 3 (Table 2 and Figure 1).

*Table2. Timing of appearance of different potential indicators of EVLW rise*

| OBSERVED TIME | No of patients with positive indicators of EVLW rise | Patients with P/F<200 (%) | Patients with dense B lines (%) | Patients with positive on both signs (%) |
|---|---|---|---|---|
| 0 | 16 | 18.5 (3) | 63 (10) | 18.5 (3) |
| 6 | 22 | 27 (6) | 46 (10) | 27 (6) |
| 12 | 28 | 3.5 (1) | 93 (26) | 3.5 (1) |
| 24 | 42 | 7 (3) | 86 (36) | 7 (3) |

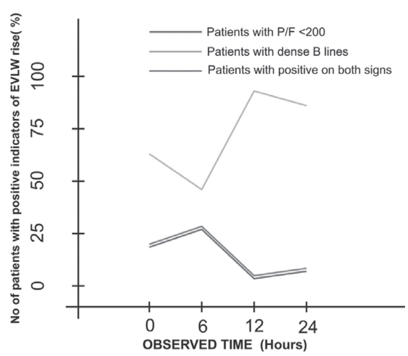


*Figure 1.*

## DISCUSSION

Here we provide evidence that lung ultrasonography can allow simple, reliable and non-invasive detection of EVLW soon after major abdominal or vascular surgery. Appearance of B-lines ≤7 mm apart on lung ultrasonography proved to predict EVLW as reliably and as early as the conventional P/F ratio. Adding information about IVCcl did not improve the ability to predict EVLW.

Perioperative fluid overload is difficult to prevent. After surgery, accumulated fluids move into the extracellular space, manifesting clinically as central and peripheral edema, such as pitting edema around ankles and periorbital swelling (23). The fluid shift in the lungs impairs gas exchange and leads to hypoxemia (24,25,26). Chest radiography, computed tomography, measurement of central venous pressure (CVP) or pulmonary artery occlusion pressure measurement (PCWP) and transpulmonary thermodilution were commonly used to gain information about pulmonary water content (27,7). Chest radiography estimation of pulmonary edema is subjective. Use of CVP, PCWP or PiCOO are invasive, can be inaccurate and require artery catheterization and central venous catheter placement.

In the situation where fluids are slightly increased, thickening of the interlobular septa and the lung interstitium create some reverberation vertical artifacts-lines, that can be detected by lung ultrasound. These lines, named B-lines, although thought to be artifacts, are clinically useful. For example, multiple diffuse B-lines with lung sliding indicate pulmonary edema. In the case of EVLW, the density of B-lines has been shown to vary proportionally with the volume of fluid in the lung and with the extent of pulmonary edema. In severe cases of EVLW, B-lines may be ≤3 mm apart (8,28,29).

In 42 of 60 patients (70%) in our study, there was no difference in how early P/F decreased below 200 or when dense B-lines appeared. This suggests that lung ultrasonography can detect EVLW nearly as early as the conventional P/F ratio. In fact, lung ultrasonography may be more sensitive than the P/F ratio: the number of patients with dense B lines increased with time in the intensive care unit, even though the number showing low P/F ratio did not (Table 2 and Figure 1). This implies that non-invasive lung ultrasound can detect an EVLW volume small enough to produce shunting of ≤20% or other clinical signs of fluid overload. If these results are verified in larger studies, it may mean that lung ultrasonography is the superior method for detecting EVLW before it becomes clinically significant.

A substantial proportion of patients in our cohort showed both dense B-lines and decreased P/F ratio on admission to the intensive care unit. We attribute this to lower functional residual capacity during surgery and to residual anesthesia-induced abdominal muscle weakness, despite the fact that we performed the recruitment maneuver at the end of anesthesia. We attribute the later appearance of decreased P/F ratio and dense B-lines to fluid excess, since muscle strength should recover during the postoperative period.

## CONCLUSION

Despite the variation in clinical manifestations of increased EVLW, it is potentially life-threatening in all cases. Our study provides evidence that lung ultrasonography is a promising non-invasive method for detecting EVLW in intensive care patients soon after major abdominal or vascular surgery. In fact, our results suggest that it may be more sensitive than the P/F ratio for early detection of fluid overload, allowing more timely initiation of antidiuretic therapy. Our findings should be verified and extended in larger studies.

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